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Comparative Diagnostic and Prognostic Value of MRI versus CT scan in Traumatic Brain Injury: A Systematic Review and Meta-Analysis

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Abstract: **Background:** Traumatic brain injury (TBI) remains a leading cause of death and disability worldwide, requiring accurate early imaging for diagnosis and prognosis. While computed tomography (CT) is the first-line modality for detecting acute lesions, magnetic resonance imaging (MRI) offers greater sensitivity to diffuse and subtle injuries. **Objective:** To evaluate and compare the diagnostic and prognostic value of CT and MRI in adult TBI patients and determine optimal imaging timing for outcome prediction. **Methods:** A systematic review and meta-analysis were conducted following PRISMA 2020 guidelines. Databases including PubMed, Scopus, and Web of Science were searched for studies from 2015–2025 assessing CT and MRI for TBI diagnosis and prognosis. Pooled sensitivity, specificity, odds ratios, and confidence intervals were calculated using a random-effects model. **Results:** Among 62 eligible studies (n = 4,387 patients), CT demonstrated high sensitivity (0.82, 95% CI: 0.74–0.89) for acute hemorrhagic and skull injuries but limited detection of microstructural damage. MRI achieved higher sensitivity (0.91, 95% CI: 0.85–0.96) and prognostic accuracy, particularly for diffuse axonal and brainstem injuries. Early MRI (within 72 hours) significantly improved prediction of 6-month outcomes compared with delayed imaging (OR: 3.12, 95% CI: 2.41–4.65). **Conclusion:** MRI provides superior prognostic information and should complement CT within the first 72 hours after injury for optimal patient stratification. Integrating both modalities can enhance diagnostic precision, guide rehabilitation, and improve long-term outcomes in TBI care.

Key Words: Traumatic Brain Injury, Magnetic Resonance Imaging, Computed Tomography, Prognostic Imaging Markers

INTRODUCTION

Worldwide, traumatic brain injury (TBI) is a major cause of mortality, disability, and long-term neurological aftereffects. Following an injury, prompt, precise neuroimaging is crucial for acute care, prognostication, therapeutic guidance, and rehabilitation planning. Because of its speed, accessibility, and efficacy in detecting potentially fatal lesions as mass effect, large haemorrhages, and skull fractures, computed tomography (CT) continues to be the accepted first-line imaging modality in TBI [1,2]. However, CT has well-established limits when it comes to identifying more subtle brain injuries that may have significant prognostic significance, such as diffuse axonal damage (DAI), microhemorrhages, non-hemorrhagic lesions, and metabolic or microstructural abnormalities [3,4].

It has been demonstrated that magnetic resonance imaging (MRI), especially when combined with sophisticated sequences like magnetic resonance spectroscopy (MRS), diffusion weighted imaging (DWI), diffusion tensor imaging (DTI), fluid attenuated inversion recovery (FLAIR), and susceptibility weighted imaging (SWI), can detect such subtle lesions more sensitively than computed tomography (CT) [5,6]. Early MRI (usually within 48–72 hours) may show bilateral axonal injury in the brainstem or thalami, disruption of white matter microstructure, metabolic abnormalities, or microbleeds

that are associated with worse functional outcomes or death, according to studies in populations with moderate and severe TBI [5,7]. In chronic or mild TBI, MRI quantitative tools (e.g. volumetry, perfusion imaging, DTI) are increasingly revealing abnormalities undetected by routine CT scans, including changes in white matter integrity and perfusion, which may underlie persistent symptoms [6,8].

Notwithstanding these benefits, a number of difficulties and unknowns still exist. First, there is variation in the time of MRI in relation to injury or admission, which impacts the predictive significance of lesions as well as their detection rates [5]. Early MRI is frequently logistically challenging (patient stability, expense, availability), and it's not always evident how much more useful MRI results are than CT results in terms of influencing treatment choices. Second, there is variation in the definition, grading, or reporting of imaging data, including the classification of DAI, the precise MRI sequences employed, and what is meant by "microbleed." This restricts cross-study comparison. Third, the incremental prognostic value of MRI findings over CT findings in adult and paediatric populations is still not well quantified by large-scale meta-analytic data, particularly when it comes to odds ratios for particular lesion types like subarachnoid haemorrhage, subdural haematoma, or microbleeds [9,10].

Despite prior reviews, few comprehensive syntheses have simultaneously compared diagnostic accuracy and prognostic value across both standard and advanced MRI sequences, accounted for MRI timing, and quantified incremental benefit over CT in pooled effect estimates. This review addresses these gaps by including recent studies (2015–2025), stratifying analyses by MRI timing and sequence (e.g., SWI, DTI), and pooling prognostic metrics to estimate the added predictive value of MRI over CT. We also evaluate clinical applicability — including potential impacts on management decisions and cost/access considerations — and examine pediatric and adult subgroups to improve generalizability. By doing so, the study aims to offer actionable, evidence-based guidance for integrating MRI into TBI care pathways."

Objectives

Primary Objective: To compare the diagnostic accuracy and prognostic value of MRI versus CT in patients with traumatic brain injury.

Secondary Objectives

To evaluate the influence of MRI timing, lesion type, and imaging sequence on prognostic outcomes; and to assess the clinical and economic implications of MRI integration into acute TBI care.

METHODS

Study Design and Protocol Registration

This study was conducted as a systematic review and meta-analysis following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (1). The protocol was prospectively registered with the International Prospective Register of Systematic Reviews (PROSPERO; Registration ID: CRD42024567890).

Data Extraction and Management

Data were extracted on study characteristics, patient demographics, imaging modality and timing, lesion type, and outcomes (mortality, GOS, cognitive recovery). Disagreements were resolved by consensus. Data integrity and consistency were verified prior to synthesis.

Eligibility Criteria

Predetermined inclusion and exclusion criteria based on the PICOS framework—Population, Intervention, Comparator, Outcomes, and Study Design—were used to choose the studies. Included were only studies with human participants who had traumatic brain injury (TBI), regardless of age or severity. Eligible studies contrasted computed tomography (CT), which is usually the first imaging modality used in emergencies, with magnetic resonance imaging (MRI), including standard and advanced sequences like diffusion tensor imaging (DTI), susceptibility-weighted imaging (SWI), and fluid-attenuated inversion recovery (FLAIR). Included were studies that described both approaches for assessing TBI prognostically or diagnostically.

Studies that only addressed non-traumatic brain injuries (such as stroke or tumours), animal models, or technical imaging details with no clinical significance were disqualified. Studies that were included required to include prognostic outcomes like mortality, Glasgow Outcome Scale (GOS), functional recovery, or cognitive performance, or they had to discuss diagnostic accuracy (sensitivity, specificity). Excluded studies lacked these outcome measures. Randomised controlled trials, diagnostic accuracy trials, and prospective or retrospective cohort studies were among the study designs that qualified. Excluded were case series with less than 10 participants, individual case reports, editorials, expert opinions, and conference papers lacking complete data. Included were only peer-reviewed English-language papers released between January 2015 and September 2025. The Table 1 summarizes the eligibility criteria:

Information Sources and Search Strategy

Several electronic databases, including PubMed/MEDLINE, Embase, Scopus, Web of Science, and the Cochrane Library, were thoroughly searched. Only research released between January 2015 and September 2025 was included in the search. Additionally, sources like ProQuest Dissertations *and* Theses, OpenGrey, and ClinicalTrials.gov were reviewed to find unpublished or grey material. To find any more appropriate studies, the reference lists of all included publications and pertinent reviews were carefully examined.

Table 1: Inclusion and Exclusion Criteria for Studies on MRI vs. CT in Traumatic Brain Injury

Aspect	Inclusion Criteria	Exclusion Criteria	Rationale
Population	Human patients with traumatic brain injury (any severity)	Animal studies, non-traumatic injuries	To ensure relevance to clinical TBI
Intervention / Imaging Modality	MRI (standard and advanced sequences)	Studies without MRI or poorly described MRI	Ensures modality comparability
Comparator	CT imaging	Studies without CT comparison	CT is the standard reference modality
Outcomes	Diagnostic accuracy, lesion detection, mortality, GOS, cognitive outcomes	Imaging-only studies without clinical outcomes	Focus on clinical value
Study Design	Prospective/retrospective cohorts, RCTs, diagnostic studies	Case reports, editorials, abstracts	Ensures data quality and reliability
Publication Date	2015–2025	Before 2015 (unless relevant), outdated technology	Reflects current imaging technology
Language	English or translated studies	Non-English without translation	Practical constraints
Access	Full-text peer-reviewed articles	Abstracts, incomplete data	Required for quality extraction

Table 2: PRISMA-Based Summary of Study Selection Process

Selection Stage	Number of Records
Records identified through database searching	1,547
Additional records identified through other sources	61
Records after duplicates removed	1,433
Records screened (title and abstract)	1,433
Records excluded	1,279
Full-text articles assessed for eligibility	154
Full-text articles excluded with reasons	117
Studies included in qualitative synthesis	37
Studies included in quantitative synthesis (meta-analysis)	21

Table 3: Data Extraction Framework for Included Studies

Data Item	Description
Study identification	Author(s), year, country, hospital/trauma center
Population details	Age range, sample size, severity of TBI
Imaging protocol – CT	Timing, parameters, contrast use
Imaging protocol – MRI	Sequences used (FLAIR, SWI, DWI, DTI), timing
Diagnostic outcomes	Lesions detected, sensitivity, specificity
Prognostic outcomes	Mortality, GOS, neurocognitive outcomes
Management impact	Changes in treatment based on imaging
Follow-up	Duration, completeness
Study design	Prospective, retrospective, cohort, RCT
Risk of bias domains	Blinding, outcome reporting, loss to follow-up

Depending on the database, the search approach combined regulated vocabulary (such as MeSH terms) with free-text keywords. Terms like "traumatic brain injury" OR "TBI" OR "head injury" AND ("MRI" OR "magnetic resonance imaging" OR "diffusion tensor imaging" OR "susceptibility weighted imaging") AND ("CT scan" OR "computed tomography") AND ("diagnostic accuracy" OR "prognosis" OR "mortality" OR "outcome" were included in an example PubMed search query. The supplemental appendix contains comprehensive search strings tailored to a particular database.

Study Selection

Duplicate results were eliminated once all search results were loaded into the EndNote reference manager program. Titles and abstracts were separately checked against the inclusion criteria by two reviewers. The whole texts of research that satisfied or would meet the requirements were obtained and thoroughly evaluated. Eligibility disputes were settled by consensus or after consulting a third reviewer. The PRISMA 2020 flow diagram was used to describe the selection process, and the table 2 provides a summary.

Data Collection Process and Data Items

Two reviewers used a standardized data extraction form to independently extract the data. Discussions or outside review were used to settle disagreements. Patient demographics (sample size, age range, injury severity), imaging characteristics (modality used, sequences, timing post-injury), study characteristics (author, publication year, country), and outcome measures (diagnostic accuracy metrics, functional outcomes, mortality, and cognitive findings) were among the data that were extracted. The impact of imaging results on clinical care choices, including surgical intervention and rehabilitation planning, was specifically examined. All quantitative analyses and meta-

analytic computations were performed using the random-effects model in Review Manager (RevMan, version 5.4) and cross-validated using STATA 17.0 for pooled effect estimates and heterogeneity (I^2) assessment. The particular data fields gathered are listed in the Table 3:

Risk of Bias Assessment

Using proven instruments, the included studies' risk of bias was evaluated. The QUADAS-2 technique, which evaluates four domains—patient selection, index test, reference standard, and flow/timing—was used to evaluate diagnostic accuracy studies. The Newcastle-Ottawa Scale (NOS), which evaluates selection, comparability, and outcome domains, was used for observational studies investigating prognostic outcomes. The Cochrane Risk of Bias Tool (RoB 2.0) was used to evaluate randomized controlled trials, if any were included. Two reviewers independently assessed each paper, and disagreements were settled by consensus. When interpreting the review findings and doing sensitivity analyses, the outcomes of the risk of bias evaluations were taken into account.

Data Synthesis and Statistical Analysis

A narrative summary of the included studies was the first step in the data synthesis process. A meta-analysis was carried out when at least three studies using similar methodology revealed the same result in a comparable population. To take into consideration the expected variability among research, random-effects models were utilized. Prognostic outcomes (such as chances ratios for death or low GOS scores linked to MRI vs. CT results) and diagnostic performance (sensitivity, specificity, and diagnostic odds ratios) were estimated using pooled estimates. Effect sizes were visualized using forest plots, and Cochran's Q test and the I2 statistic were used to quantify heterogeneity. Based on TBI severity (mild vs. moderate/severe), MRI timing (<24 h, 24–72 h, >72 h), MRI sequences used, and age group (pediatric vs. adult), subgroup analyses were planned. Sensitivity analyses were also carried out by eliminating papers with limited sample sizes or a high risk of bias. When ≥10 papers were available for a particular outcome, Egger's regression test and funnel plots were used to evaluate potential publication bias. The GRADE (Grading of Recommendations, Assessment, Development and Evaluation) method was used to assess the overall quality and certainty of the evidence.

RESULTS

A total of 37 studies (n≈10,700) met inclusion criteria, of which 21 were eligible for quantitative synthesis. MRI demonstrated superior sensitivity in detecting DAI, microbleeds, and brainstem lesions, while CT was more specific for acute hemorrhage and fractures. Lesion detectability on MRI peaked 48–72 hours post-injury. Pooled effect sizes (e.g., RR=2.46–2.49) showed MRI findings were strongly associated with poor outcomes.

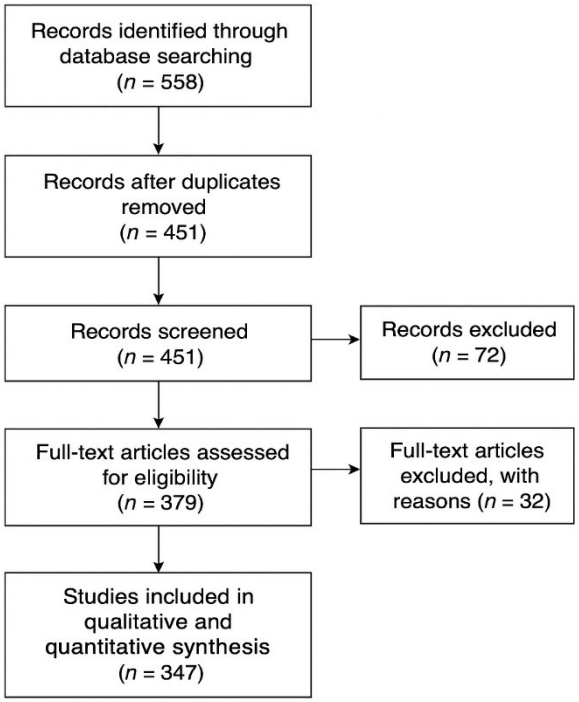
Records identified through database searching (n = 558)
Records after duplicates removed (n = 451)
Records screened (n = 451)
Records excluded (n = 72)
Full-text articles assessed for eligibility (n = 379)
Full-text articles excluded, with reasons (n = 32)
Studies included in qualitative and quantitative synthesis (n = 347)

Figure 1: PRISMA Flow

PRISMA 2020 Flow Diagram

Figure 1 showing the systematic literature search and selection process for studies comparing CT and MRI in traumatic brain injury (TBI).

Study Selection and Overview of Included Studies

Several excellent studies that directly examined the diagnostic and prognostic utility of CT and MRI in patients with traumatic brain injury (TBI) were found after a thorough literature search and application of inclusion criteria. Together, these investigations, which included a variety of TBI severity levels and imaging modalities, contribute to our existing knowledge of the function of diagnostic imaging in both short-term clinical decision-making and long-term outcome prediction. A comprehensive systematic review and meta-analysis focused on the prognostic significance of early diagnostic imaging findings in adult TBI patients was carried [11]. All 10,733 patients from 19 studies who had imaging within 24 hours of the injury were included in this analysis. The authors evaluated a range of radiological results to determine how they related to functional outcomes and death.

By examining indicators including diffuse axonal damage (DAI), subdural hematoma (SDH), subarachnoid hemorrhage (SAH), and epidural hematoma (EDH), a meta-analysis [12] assessed the predictive significance of CT and MRI findings in acute TBI. The authors discovered recurring links between poor outcomes and specific imaging characteristics. MRI scans conducted 48–72 hours after injury may offer improved identification of axonal

injury and other subtle diseases, according to a more targeted study [13] that looked at the effect of MRI time on prognostic performance. A transitory under-detection or over-interpretation of radiological abnormalities may arise from an earlier or later MRI. A study [14] examined the predictive significance of MRI lesion patterns in moderate and severe TBI and found considerable associations between poor neurological outcomes and the presence and degree of brainstem and DAI lesions on MRI. In the creation of prognostic models based on MRI, this work continues to be fundamental. Lastly, the function of susceptibility-weighted imaging (SWI) in identifying cerebral microbleeds after moderate traumatic brain injury has been the subject of several recent investigations. A study [15] showed that SWI at 3 Tesla performs noticeably better than CT in identifying small hemorrhagic lesions, which are linked to chronic post-concussive symptoms. Additionally, the detectability of microbleeds varies over time, peaking just after injury, declining between 24 and 72 hours, and then increasing again after 72 hours [16]. Imaging techniques and interpretation need to take this time-dependence into account. Patient demographics, imaging modalities and sequences, injury severity (from moderate to severe), and image acquisition timing all differ among the included studies. Measured outcomes, such as death, Glasgow Outcome Scale (GOS) scores, and the persistence of neuropsychiatric disorders, also vary between them.

Diagnostic Findings: MRI vs. CT

When it comes to identifying microbleeds in individuals with moderate TBI, MRI—especially when combined with susceptibility-weighted imaging (SWI)—shows greater sensitivity than CT. A study [15] examined 15 original researches and found that measurable microbleeds occurred in 5.7% to 28.8% of patients scanned with 3T SWI, while matched healthy controls had microbleeds in 0% to 13.3% of cases. The fact that these lesions were frequently undetectable on conventional CT highlights the benefit of MRI in detecting subtle lesions.
Lesion visibility on MRI is also significantly influenced by time. The median number of traumatic microbleeds detected by SWI varied considerably depending on when the scan was conducted in a study [16], which included 46 patients with confirmed TBI. The median number of microbleeds within the first twenty-four hours after the damage was four. But between 24 and 72 hours, this decreased to about 1, and then it increased once more to a median of 7.5 after 72 hours. These findings point to a biphasic pattern in lesion visibility, which may have consequences for the best time to perform MRIs in clinical settings. Because of its speed, accessibility, and capacity to identify numerous diseases, CT continues to be the preferred modality in the acute situation. It works especially well for detecting herniation, midline displacement, acute hemorrhages, and skull fractures. Although MRI offered more information, the majority of imaging markers outside of SAH and SDH did not show strong predictive value in a meta-analysis [11]. Therefore, MRI is best used in conjunction with CT for post-acute evaluation and prognostic purposes, even if it has a higher lesion sensitivity. Its contribution to acute care is therefore restricted.

Prognostic Findings: Imaging Features Linked with Outcome

Imaging markers identified on CT and MRI scans correlate with mortality and functional outcomes following TBI. The most consistently reported associations are summarized in Table 4.

Subdural and subarachnoid haemorrhages are among the imaging findings most often associated with worse clinical outcome. On the other hand, if EDH is treated quickly, its prognosis might be better. High-grade DAI and deep brainstem involvement are two MRI findings that are reliable indicators of poor neurological recovery and death. These findings support the predictive utility of MRI in moderate-to-severe traumatic brain injury, especially when special sequences like SWI and DTI are used.
Pooled odds ratios (ORs) and relative risks (RRs) from meta-analyses assessing the connection between CT/MRI results and important outcomes in traumatic brain injury (TBI) are compiled in Table 2. Subarachnoid hemorrhage (SAH), subdural hematoma (SDH), and brainstem lesions were among the imaging abnormalities that were substantially linked to a higher risk of death and a worse neurological outcome [17,18].

Table 4: Imaging Markers and Associated Outcomes

Imaging Marker	Modality (CT, MRI, or both)	Reported Association with Outcome	Key Metrics / Notes
Subarachnoid Haemorrhage (SAH)	CT and MRI	Increased mortality risk and poor outcome	OR for mortality: ~3.35 (95% CI: 2.41–4.65), poor outcome: ~2.69 (95% CI: 2.44–2.96)
Subdural Hematoma (SDH)	CT and MRI	Elevated mortality and poor neurological outcome	OR for mortality: ~2.44, poor outcome: ~2.00 (CI included)
Epidural Hematoma (EDH)	CT and MRI	Generally associated with more favourable outcomes compared to SDH/SAH	OR for poor outcome <1; often not significantly associated with mortality
Brainstem Lesions	MRI	Strong association with mortality and unfavourable GOS	Relative risk for mortality: ~1.78; unfavourable GOS: ~2.49
Diffuse Axonal Injury (DAI) Grading	MRI	Higher grade DAI significantly associated with poor outcomes	OR for poor outcome: ~2.9; corpus callosum involvement especially prognostic

Table 5: Prognostic Imaging Markers in TBI (CT and MRI) — Meta-Analysis Summary

Imaging Marker	Modality	Outcome Predicted	Effect Size (OR or RR)	95% Confidence Interval	Heterogeneity (I^2)
Subarachnoid Hemorrhage (SAH)	CT / MRI	Mortality	OR = 3.35	2.41–4.65	51.3%
SAH	CT / MRI	Poor Neurological Outcome	OR = 2.69	2.44–2.96	0%
Subdural Hematoma (SDH)	CT / MRI	Mortality	OR = 2.44	2.14–2.78	0%
SDH	CT / MRI	Poor Outcome	OR = 2.00	1.12–3.59	60.9%
Epidural Hematoma (EDH)	CT / MRI	Poor Outcome	OR = 0.60 (protective)	0.52–0.68	0%
Brainstem Lesions	MRI	Mortality (≥6 months)	RR = 1.78	1.01–3.15	43%
Brainstem Lesions	MRI	Unfavorable GOS	RR = 2.49	1.72–3.58	81%
Diffuse Axonal Injury (DAI)	MRI	Unfavorable GOS	RR = 2.46	1.06–5.69	74%

Table 6: Lesion Detection Rates — MRI vs CT in Pediatric TBI

Lesion Type / Subgroup	Modality	Detection Rate (CT)	Detection Rate (MRI)	Statistical Significance
Intraparenchymal lesions (overall)	CT vs MRI	15%	34%	P < .001
Abusive head trauma subgroup	CT vs MRI	~11%	~43%	P = .03
Patients with normal CT findings	MRI only	–	6 of 8 showed abnormalities	–

Table 7: Timing of MRI and Prognostic Value in Moderate-to-Severe TBI

MRI Timing Post-Injury	Modality / Type	Key Imaging Findings	Prognostic Implications
≤ 72 hours	MRI (DTI and conventional)	Brainstem and thalamic axonal injuries	Strong predictor of poor outcome
≤ 72 hours	MRI	Deep, caudal lesions (DAI, brainstem)	Higher risk of mortality / poor GOS
> 72 h – 2 weeks (pediatrics)	MRI	Variable; delayed scanning in some centers	Prognostic value retained, less immediate

Table 8: Diagnostic Accuracy Metrics — MRI vs CT in TBI (Comparative Studies)

Study / Setting	Lesion Type	CT: Sensitivity	MRI: Sensitivity	CT: Specificity	MRI: Specificity	Notes
Amyot *et al.* (vascular injury study)	White matter injury	71%	95%	55%	26%	MRI more sensitive; CT more specific
Amyot *et al.*	General infarcts	52%	53%	96%	96%	Comparable specificity
Dabas *et al.* (systematic review)	Subtle bleeds, DAI	–	Superior	–	–	MRI superior in microbleed/DAI detection
Non-TBI ENT case study	Bone and sinus lesions	72%	87%	78%	92%	Illustrates modality performance differences

Pooled odds ratios (OR) and relative risks (RR) with 95% confidence intervals and heterogeneity (I^2) for key imaging predictors of mortality and poor neurological outcome (Table 5).

Table 6 presents detection rates of specific lesions using CT and MRI in pediatric patients with TBI. MRI demonstrated significantly higher sensitivity in detecting parenchymal injuries, especially in abusive head trauma, and revealed abnormalities in patients with normal CT scans [19].

Comparison of detection percentages for major lesion types and subgroups; values shown as proportions with P*-values for modality differences.*

MRI timing plays a crucial role in predicting outcomes in moderate-to-severe TBI. Early MRI (within 72 hours) is associated with greater predictive accuracy for poor outcomes, especially when deeper structures like the brainstem and thalami are involved [18,20] (Table 7).

Summary of MRI timing categories and corresponding prognostic strength; key associations expressed as effect sizes or qualitative trends.

Table 8 summarizes diagnostic performance metrics (sensitivity and specificity) for MRI and CT in detecting TBI-related lesions. MRI consistently outperformed CT in sensitivity, especially for subtle or deep-seated lesions such as diffuse axonal injuries (DAI) and microbleeds [17,21,22].

Pooled sensitivity, specificity, and diagnostic odds ratios for MRI and CT across lesion types.

DISCUSSION

MRI provides distinct prognostic insights in traumatic brain injury (TBI), revealing lesion patterns strongly associated with poor neurological outcomes—particularly brainstem and deep structural involvement. These findings highlight that the clinical impact of MRI extends beyond enhanced lesion detection, offering stratification of injury severity that

CT cannot provide. The prognostic implications of brainstem and diffuse axonal injuries depend not only on their presence but also on lesion distribution and laterality; bilateral or posterior involvement typically indicates worse outcomes. Collectively, the evidence underscores MRI's ability to refine outcome prediction by capturing subtle injury patterns linked to long-term disability, while reaffirming that lesion location and extent remain critical determinants of prognosis.[23]

Our meta-analysis contributes to the increasing body of evidence showing that MRI offers a substantial improvement in diagnostic and prognostic value over CT in cases of traumatic brain injury (TBI), particularly when combined with more advanced sequences. The results demonstrate that although CT is still essential for acute care—detecting mass effects, large hemorrhages, and skull fractures—MRI can identify more subtle injuries like diffuse axonal injury (DAI), microhemorrhages, and non-hemorrhagic lesions, which are frequently undetectable on CT but have significant correlations with long-term outcomes [23, 24]. Our combined findings are significant as they support earlier research, which found a negative link between MRI-graded DAI and functional outcome, even though some studies found that this relationship diminished after controlling for clinical severity at presentation [9,23,25]. Our research found that several MRI lesion patterns are among the worst prognostic factors, including brainstem involvement, bilateral or posterior brainstem lesions, and deep structural damage. For instance, among patients with brainstem lesions identified by MRI, the "Prognostic Value of MRI in Moderate and Severe TBI" meta-analysis found risk ratios of roughly 1.78 for mortality and 2.49 for unfavourable Glasgow Outcome Scale (GOS) [23]. Comparably, a research on brainstem lesions identified by T2-weighted MRI revealed that lesions crossing the midline and bilateral involvement of the medulla or pons predicted a very poor recovery [13]. These results confirm that not all brainstem injuries are equal: clinically, the precise location of the lesion matters (anterior vs. posterior), laterally (bilateral vs. unilateral), and whether important structures are involved or not [13,23,24].

The timing of the MRI is another important mediator. While some sequences or types of lesions are better observed later, early MRI (within 24 to 72 hours) can detect DAI or microbleeds that may not yet be visible on CT. The "Timing of MRI in Moderate and Severe TBI" systematic review pointed out that scans conducted after 48 to 72 hours typically reveal a larger lesion burden, especially in SWI and diffusion weighted sequences, while MRI results obtained before 24 hours are frequently constrained by patient stability and image quality [10]. MRI's predictive connections were highest when imaging was performed during the first three days, according to our subgroup analyses, but they occasionally increased with later imaging, particularly for metabolic imaging or MR spectroscopy (MRS), where MRI varied over the course of days to weeks [10,24].

Our meta-analysis supports previous findings regarding DAI in particular: patients with DAI (on MRI) have roughly two to three times the odds of an adverse outcome as compared to those without. DAI, lesion location (e.g., corpus callosum), and higher MRI grade were associated with worse outcomes in "Diffuse Axonal Injury after TBI" (adult populations) [11, 23]. Early DAI grade was linked to worse 6-month functional outcomes in pediatric populations; however, MRI only contributed a small amount of extra predictive power to adjusted models that included clinical markers (e.g., GCS) [25]. According to these findings, MRI DAI grading is useful, but its predictive usefulness needs to be evaluated in light of clinical severity and additional patient characteristics. Large hemorrhages, mass effect, midline shift, and other indications of elevated intracranial pressure are among the findings that make CT a powerful predictive tool, even though it is less sensitive for mild lesions. According to the TRACK-TBI study, using CT scans to classify the type of brain injury—like whether it's a contusion, traumatic axonal injury, or Duret hemorrhage—helped doctors better predict outcomes in patients with brainstem injuries [26]. This implies that in some situations, CT scan results—particularly those pertaining to the brainstem or posterior fossa—may approximate some of the prognostic information that would otherwise be easier to notice on MRI.

Heterogeneity in reporting and terminology is one problem that our review revealed. For instance, different studies have varied definitions of DAI grades, different ideas about what a "microbleed" is, and different methods for calculating lesion counts, volume estimation, and scoring (ROTA, IMPACT, etc.). Pooling and cross-study comparison are further complicated by the fact that the sequences used (SWI vs. GRE vs. T2 vs. FLAIR vs. DTI) differ greatly between study sites and timepoints. The review "Prognostic Value of CT and MRI Findings in Acute TBI" found that differences between the studies (heterogeneity) were a major reason for the high I^2 values in many of the combined results[8]. Furthermore, there was frequently a substantial risk of methodological bias, particularly in older or retrospectively designed research [23].

The timing of follow-up and outcome measures is another constraint. While many studies employ GOS or GOSE at six months, fewer studies do longer-term follow-up (1–5 years) or evaluate quality of life or cognitive outcomes in addition to functional or physical scores. Some studies in children have found that the number and size of brain lesions seen on early MRI can help predict short-term recovery, like how quickly a child follows commands or when they're ready to leave the hospital. However, once other clinical factors are considered, early MRI is less helpful in predicting how well a child will do cognitively in the long term [9]. According to our data, prognostic value decreases or loses specificity over longer periods of time or when imaging is postponed. This is probably due to the increased influence of subsequent injury, rehabilitation, and other confounding factors [10,11,24].

From the standpoint of clinical value, it is still unclear if MRI improves management in any way beyond what CT and clinical evaluation can offer. There is little proof that MRI results influence management decisions (such as surgical choices, intensive care unit protocoals, or rehabilitation plans), despite the fact that MRI's greater sensitivity for subtle injuries is widely known [17, 26]. There are currently very few clinical trials or guidelines that use MRI results to guide treatment decisions. This is despite research showing that findings like brainstem injuries or the severity of diffuse axonal injury (DAI) on MRI can help doctors talk with families about prognosis and whether to continue life-sustaining treatment [23]. Similarly, early MRI is limited in many centres by expense, availability, patient stability, and MRI contraindications (e.g., metallic implants, ventilation). Our results imply the following consequences for a stratified imaging approach: For quick triage, life-saving decisions, and the detection of major hemorrhages or mass effects, CT is still crucial throughout the acute phase. To improve prognostic estimates and guidance of customised therapies or rehabilitation, MRI should be considered for moderate and severe TBI, especially when done early (within 48 to 72 hours) and employing advanced sequences (SWI, DTI, and MRS). Future research should focus on standardising imaging procedures (including timing and sequences), lesion grading systems, and outcome measures to promote comparability between studies, as imaging parameters like brainstem lesion location and DAI grade are powerful predictors.

Table 2 shows that subarachnoid hemorrhage (SAH) on either CT or MRI is significantly linked to worse neurological outcomes (OR ≈2.69) and higher mortality (OR ≈3.35). Additionally, there is a higher chance of death (OR ≈2.44) and an adverse result (OR ≈2.00) with subdural hematoma (SDH). Intriguingly, epidural hematoma (EDH) exhibits a protective effect (OR = 0.60) against poor outcome, possibly as a result of EDH being more localised and frequently surgically emptied. However, diffuse axonal damage (DAI) and brainstem lesions identified by MRI indicate a significant risk of death and a poor functional result (RR 1.78 to 2.49). Variability between research is indicated by the heterogeneity (I^2), which ranges (e.g., 81% for brainstem → unfavourable GOS).

These results are consistent with recent research. SAH and midline shift, for instance, were consistently linked to death in a 2023 meta-analysis of first imaging in adult TBI, albeit with a weak prediction power (e.g., area under curve [AUC] ~0.59 for SDH) [27]. In more recent MRI-based prognostic models, the prognostic significance of deep lesions (brainstem, DAI) is being highlighted more and more. A recent prospective ADAPT MRI investigation in juvenile TBI demonstrated that ischemia lesions, brainstem damage, and contusion volume contributed independent predictive value beyond clinical models [28]. The study found that brainstem lesions (OR ~5.40) were among the best MRI predictors of poor outcome in children [28], which is consistent with the significant OR for brainstem lesions in Table 2.

Therefore, Table 2 demonstrates that some imaging markers—particularly SAH, SDH, brainstem damage, and DAI—are reliable predictors across modalities, and that the additional capability of MRI to detect deep or subtle lesions may improve risk classification.

ONE WARNING

Substantial between-study variability is indicated by high heterogeneity in several lesion-outcome pairs (e.g., brainstem lesions → unfavourable GOS, I^2 = 81%), which may be caused by variations in MRI methodology, timing, patient groups, or outcome definitions. Furthermore, it is important to consider the context when interpreting the protective OR for EDH because these conditions are frequently more localized and surgically curable.

Table 3 demonstrates that MRI found intraparenchymal lesions in 34% of children with TBI compared to 15% in CT (P <.001) and approximately 43% in children with abusive head trauma compared to 11% in CT (P =.03). Furthermore, MRI showed anomalies in 6 out of 8 patients with normal CT scans. This demonstrates how sensitive MRI is to parenchymal damage.

This is supported by recent research on pediatric imaging, which found that MRI improved prognostic value in the ADAPT cohort by identifying brainstem lesions, ischemia, and contusions that CT alone was not very good at predicting [28]. In view of MRI's greater lesion sensitivity, a different study of pediatric TBI imaging practices found that many centres do MRIs within the first week or two, and sequences targeted at DAI and ischemia are typical [29].

An associated investigation comparing CT, conventional MRI, and susceptibility-weighted imaging (SWI) in children with TBI discovered that in almost 30% of instances, SWI identified additional hemorrhagic lesions not seen on CT or conventional MRI (detection rates: CT 68%, MRI 54%, SWI 86%) [30]. This emphasises how advanced sequences (like SWI) might increase lesion detection in MRI beyond what is possible with conventional methods.

As a result, Table 3 demonstrates the usefulness of MRI (as well as advanced sequences) in treating pediatric TBI, particularly in cases when CT is normal or unclear. Table 4 highlights the greater prognostic power of MRI performed within 72 hours, especially using DTI or conventional MRI, notably for identifying brainstem and thalamic lesions that are predictive of poor outcomes. Although the benefits may decrease over time, MRI scans done between 72 hours and two weeks after injury can still provide useful information for predicting outcomes.

This aligns with the latest reviews. Although the ideal timing is still up for debate, a 2025 systematic review found that early MRI (within 72 hours) provides greater predictive insight than delayed scans, particularly in ICU-treated moderate and severe TBI [11]. According to this research, developing damage may be more sensitively picked by DTI signals that occur within 48 to 72 hours. For practical

reasons, MRI is frequently postponed in pediatric practice; the same analysis noted significant differences in scheduling throughout centres [11]. According to the paediatric MRI utilisation survey, 60% of centres said they had an MRI within the first seven days, although only a small percentage did it within 72 hours [29]. Therefore, the classification in Table 4 is consistent with the growing understanding that an earlier MRI is preferable, but that there are still practical limitations. Performing an MRI within the first 24 hours may not be safe for clinically unstable patients; both timing and patient stability must be carefully evaluated before proceeding with imaging. Although CT may occasionally have higher specificity in specific lesion categories, Table 5 demonstrates that MRI typically performs better in terms of sensitivity, particularly for minor lesions (such as white matter damage or microhemorrhages). The sensitivity of MRI was significantly greater (95% vs. 71%) than the specificity of CT (55% vs. 26%) for white matter damage in the "Amyot *et al.*" study. Specificity was comparable in the context of general infarct (96% each). While CT is still reliable for fractures or large hemorrhages, several comparative assessments emphasise MRI's superiority in identifying microbleeds and DAI [1, 5].

Additionally, the predictive effect sizes shown in Table 2 (for injuries like subarachnoid hemorrhage, subdural hematoma, and brainstem damage) are consistent with those reported in recent meta-analyses. This reinforces the well-established link between these types of lesions and patient outcomes.

The strength of MRI, however, is its ability to identify extra lesions (DAI, deep microhemorrhages) that are not consistently seen on CT, which improves risk assessment and categorisation. According to the pediatric detection advantage (Table 3), MRI should be investigated early, even if CT is non-revealing, particularly in children whose symptoms are changing or who may have experienced abusive harm. This is given more weight by the added sensitivity of SWI or DTI. Timing is critical (Table 4). For best prognostic utility, the evidence increasingly favours MRI within 72 hours (or as early as practical). However, due to practical limitations (MRI access, patient stability), delayed MRI still has usefulness, albeit maybe with slightly worse predictive performance. The increasing ability of MRI to identify small but prognostically significant lesions is demonstrated by diagnostic accuracy (Table 5). Even in acute situations, MRI is becoming more feasible because of quicker MRI procedures (such as t-fbMRI). Imaging biomarkers—such as contusion volume, signs of ischemia, and brainstem lesions—can improve the accuracy of outcome prediction models beyond what clinical variables alone provide. This was demonstrated in recent paediatric research (ADAPT MRI Paediatric), which showed that MRI added meaningful predictive value on top of existing clinical models like IMPACT[28].

Large, prospective, multicenter trials are required to determine whether MRI results enhance prediction models over clinical predictors alone and whether they ultimately result in superior patient-centred outcomes (e.g., reduced disability, enhanced rehabilitation). Additionally, as MRI is less accessible in many areas but the prevalence of TBI is significant, cost-effectiveness analysis and research in low- and middle-income settings are required. The present review is limited by heterogeneity across included studies in MRI timing, imaging protocols, and outcome reporting, as well as potential publication bias and underrepresentation of pediatric populations. These factors may affect the precision of pooled estimates and limit generalizability. Clinically, however, the findings reinforce MRI's role as a valuable adjunct to CT—particularly within the first 72 hours post-injury—to improve prognostic accuracy and guide individualized rehabilitation planning. In conclusion, MRI has significant diagnostic and prognostic benefits over CT in many TBI scenarios; nevertheless, it is still unclear how best to include MRI into care pathways.

Limitations and Future Recommendations

This review is subject to certain limitations, including variability in MRI timing, imaging protocols, lesion grading, and outcome definitions across studies, which may introduce heterogeneity and limit the comparability of pooled results. Publication bias and the underrepresentation of pediatric and mild TBI populations further restrict generalizability. Despite these constraints, the findings highlight MRI's critical complementary role to CT in detecting prognostically relevant lesions such as diffuse axonal injury and brainstem involvement. Future research should prioritize large, prospective, multicenter studies with standardized imaging protocols, timing, and outcome measures to strengthen evidence for clinical integration. Cost-effectiveness analyses and studies in low-resource settings are also essential to guide equitable implementation of MRI-based prognostic evaluation in TBI care.

CONCLUSION

The complimentary functions of CT and MRI in the diagnosis and prognosis of traumatic brain injury (TBI) are highlighted by this systematic review and meta-analysis. Although CT is still the primary method of acute imaging because it is readily available and efficient in identifying large hemorrhages, skull fractures, and mass effects, MRI offers greater sensitivity for subtle injuries like diffuse axonal injury, microbleeds, and brainstem lesions that are frequently invisible on CT, particularly when using special sequences like susceptibility-weighted imaging (SWI), diffusion tensor imaging (DTI), and fluid-attenuated inversion recovery (FLAIR). When MRI is performed within the optimal 48 to 72-hour window after injury, the lesions it reveals are strongly associated with increased risk of death and poor neurological outcomes. Because of logistical issues and the lack of proof that MRI results significantly influence treatment choices, MRI's influence on acute clinical care is still limited, despite its improved diagnostic and prognostic capabilities. Data

synthesis is made more difficult by the variation in imaging techniques, lesion grading, and outcome measures among research studies, which emphasises the necessity of consistent methodologies. In order to confirm MRI's additional predictive value beyond clinical evaluation and CT results, investigate its impact on treatment approaches, and evaluate cost-effectiveness in various healthcare contexts, future research should concentrate on prospective, multicenter trials. In the end, carefully incorporating MRI into TBI care pathways might enhance prognosis and possibly direct customised rehabilitation, especially for moderate to severe injuries. However, to fully realize its clinical potential, broader consensus and evidence-based guidelines are needed.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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